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SNAP-BACK ANALYSIS OF VIPER.(U)
JUL 77 G E PATRICK , J RICHARDSON

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TECHNICAL REPORT TL-77-7

SNAP-BACK ANALYSIS OF VIPER

U.S. ARMY MISSILE RESEARCH AND DEVELOPMENT COMMAND

Ground Equipment and Missile Structures Directorate
Technology Laboratory

15 July 1977

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This report presents the results of a snap-back analysis of the VIPER warhead. A description of the approach used to model this event is presented.

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CONTENTS

I. INTRODUCTION

Under a large positive axial acceleration field, a rocket will compress along its length similar to a shaft under Eulerian loading. The strain energy stored will cause a return to the undeformed configuration if the acceleration decay is sufficiently smooth (Figure 1). If, however, the acceleration is rapid, as shown in Figure 2, an oscillation will result about the abcissa. In these figures the acceleration profiles are shown in the insert while the corresponding displacements appear in the main figures. If a rocket with a steep acceleration decay also possesses a flexible or loose joint, it is conceivable that its snap-back response can be destabilizing.

The VIPER has all of the characteristics previously cited. It has a very high peak acceleration, a fairly steep acceleration decay, and a joint which appears to have little stiffness in the axial downrange direction. Additionally, flight tests have indicated a relatively high rocket-to-rocket dispersion. All of these characteristics led the VIPER Project Office to request a snap-back analysis. This report describes the approach used to model this event and presents some of the results.

II. APPROACH

The analysis of the VIPER snap-back phenomenon was conducted in two phases. The purpose of these analyses was to determine the snap-back forces in the magneform joint. Tests performed earlier indicated that forces of 5000 lb or greater would cause joint separation which, in turn, may result in flight destabilization. Because the stiffness of the joint in tension could not readily be calculated, it was assumed to be the same as in compression. Then, knowing the displacement at the joint, the force imposed on the joint could be computed. First, a detailed finite element static analysis was made to determine deflection versus length produced by the launch acceleration of 7000 g imposed as a static load. This model is presented in Figure 3. Next, a lumped parameter model was formulated for the dynamic analysis (Figure 4) and checked against the more complex static model by imposing the launch acceleration statically and comparing the resulting deflection field with that derived using the finite element procedure. Finally, the acceleration curve was approximated by a piecewise linear function and was imposed on the dynamic model.

III. STATIC ANALYSIS

The static analysis employed a finite element program, AMG054, which analyzes stresses and deflections due to symmetric loading on a body of revolution. The program is capable of accommodating a large number of degrees of freedom (in this case, 2160). AMG054 predicts the stress and displacement due to bending and axial loading. Figures 3, 5, 6 and 7 show the AMG054 model and the warhead details. The loading

was defined as a distributed axial load with a magnitude

$$7000\ g \int_0^L m(x)dx \qquad (1)$$

and a fore-to-aft direction. Figure 8 shows the deformed configuration resulting from the 7000-X 386-lb force. Displacements were multiplied by 100 for "visualization."

IV. DYNAMIC ANALYSIS

The dynamic model (Figure 4) is a lumped parameter system where the mass of the structure is concentrated at discrete points along the length, and its stiffness is represented by massless rods. The equations of motion of this structure form a coupled system of five second-order differential equations with constant coefficients. This system may be written symbolically as

$$m_{ij}\ddot{x}_j + k_{ij}\ x_m = F_i(t) \qquad i,j = 1, 2, \ldots, 5 \quad . \qquad (2)$$

The stiffness of the ith rod is defined as

$$k_i = \frac{A_i E_i}{L_i} \quad , \qquad (3)$$

where A_i is the cross-sectional area of the rod, L_i is its length, and E_i is the Young's modulus of the material.

Next, the equations of motion are written as the system of 10 first-order differential equations as follows:

$$DV(2)/Dt = V(3)$$

$$DV(3)Dt = \frac{1}{m_1}\left[-k_1 V(2) + k_1 V(4)\right] + g(t)$$

$$DV(4)/Dt = V(5)$$

$$DV(5)/Dt = \frac{1}{m_2}\left[k_1 V(2) - (k_1 + k_2)V(3) - k_2 V(6)\right] + g(t)$$

$$DV(6)/Dt = V(7)$$

$$DV(7)/Dt = \frac{1}{m_3}\Big[k_2V(4) - (k_2 + k_3)V(6) + k_3V(8)\Big] + g(t)$$

$$DV(8)/Dt = V(9)$$

$$DV(9)/Dt = \frac{1}{m_4}\Big[k_3V(6) - (k_3 + k_4)V(8) + k_4V(9)\Big] + g(t)$$

$$DV(10)/Dt = V(11)$$

$$DV(11)/Dt = \frac{1}{m_5}\Big[k_4V(8) - (k_4 + k_5)V(10)\Big] + g(t) \quad , \qquad (4)$$

where g(t) is the acceleration profile described in Figure 9, and

$$V(1) = t = \text{Time}$$

$$V(2) = x_1$$

$$V(3) = \dot{x}_1$$

$$V(4) = x_2$$

$$V(5) = \dot{x}_2$$

$$V(6) = x_3$$

$$V(7) = \dot{x}_3$$

$$V(8) = x_4$$

$$V(9) = \dot{x}_4$$

$$V(10) = x_5$$

$$V(11) = \dot{x}_5 \quad . \qquad (5)$$

Computer programs INTERP and SSIMDE were used.[1] INTERP performs an interpolation of the piecewise linear functions g(t) for each time step in the integration procedure. SSIMDE employs the Runga Kutta technique to integrate Equation (4). The program used for data input and graphics is shown in the appendix.

To check this procedure, a five-lumped parameter model of a uniform beam was constructed. Figure 10 shows the model and significant para-parameters, while Figures 11 through 15 show the displacements for m_1 through m_5. The overall displacement computed was 0.0454 in., while the closed form solution was 0.0438 in. Because the error was only 3.6%, the model appears accurate.

The VIPER warhead model masses and stiffnesses were calculated and a trial run was made. A run was made with g(t) increasing to 2.702×10^6 lb and remaining at that level until the displacements of the model reached a stable value for all masses. The resulting displacements were compared to the finite element predictions and corrected accordingly.

Finally, four acceleration profiles were considered:

a) Case 1 - g(t) decays linearly from 0.0055 to 0.03 sec.

b) Case 2 - g(t) decays linearly from 0.0055 to 0.01 sec.

c) Case 3 - g(t) decays linearly from 0.0055 to 0.006 sec.

d) Case 4 - g(t) decays linearly from 0.0055 to an acceleration of 1250 g at 0.008 sec and then to 0 at 0.01 sec.

V. RESULTS AND CONCLUSIONS

The displacements resulting from the four cases are shown in Figures 16 through 19. Cases 1, 2, and 3 were performed to investigate the sensitivity of the snap-back forces and displacements to the slope of the decay portion of the acceleration curve. Case 4 is a fairly accurate representation of the actual acceleration profile. Table 1 presents the maximum negative displacements at mass number five which occur at snap-back in each case and the corresponding force in the joint.

---

[1] Sellers, W. R., Jr. and Gibbs, B. G., Descriptions-General-Purpose Computer Subroutines, US Army Missile Command, Redstone Arsenal, Alabama, January 1975, Addendum - January 1977, Report No. TR-WS-75-2.

TABLE 1. MAXIMUM NEGATIVE DISPLACEMENTS AT MASS NUMBER 5.

Case	$-X_5$ (Max)	F_5 (Max)
1	-0.00007	800.0
2	-0.00076	987.5
3	-0.00142	1851.0
4	-0.00101	1322.1

The obvious conclusion is that the snap-back force increases as the slope of the acceleration decay curve increases. Another run was made at one-half the period of the fundamental longitudinal natural frequency. This resulted in an extremely large deflection (-0.01010 in.) and force on the joint (13,130 lb).

Case 4 is a realistic representation of the actual acceleration profile. The predicted load at the joint is lower than 5000 lb and is, therefore, of insufficient magnitude to cause separation. However, it must be cautioned that if the decay period approaches one half of the fundamental longitudinal frequency, the excursion and, consequently, the force, will become very high.

Still another factor which should be considered in future work is the motor case weight. Since the motor case is approximately equal to the forward portion of the rocket a model of the entire rocket should be developed and tested. Unfortunately there was not time to accomplish this during this effort.

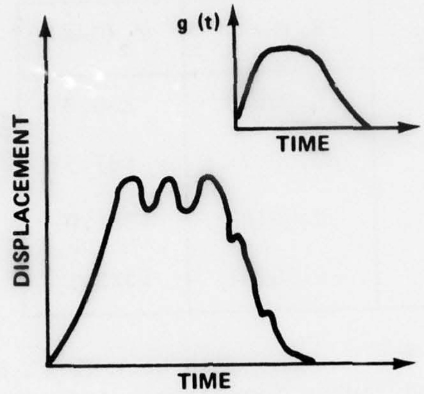

Figure 1. Smooth acceleration decay.

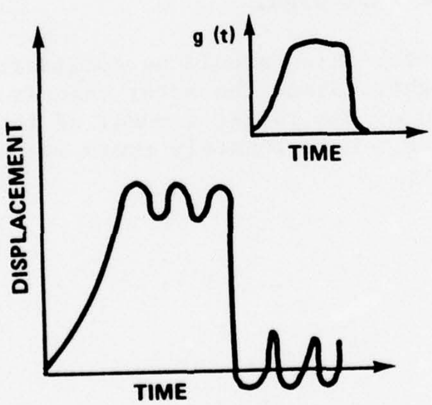

Figure 2. Steep acceleration decay.

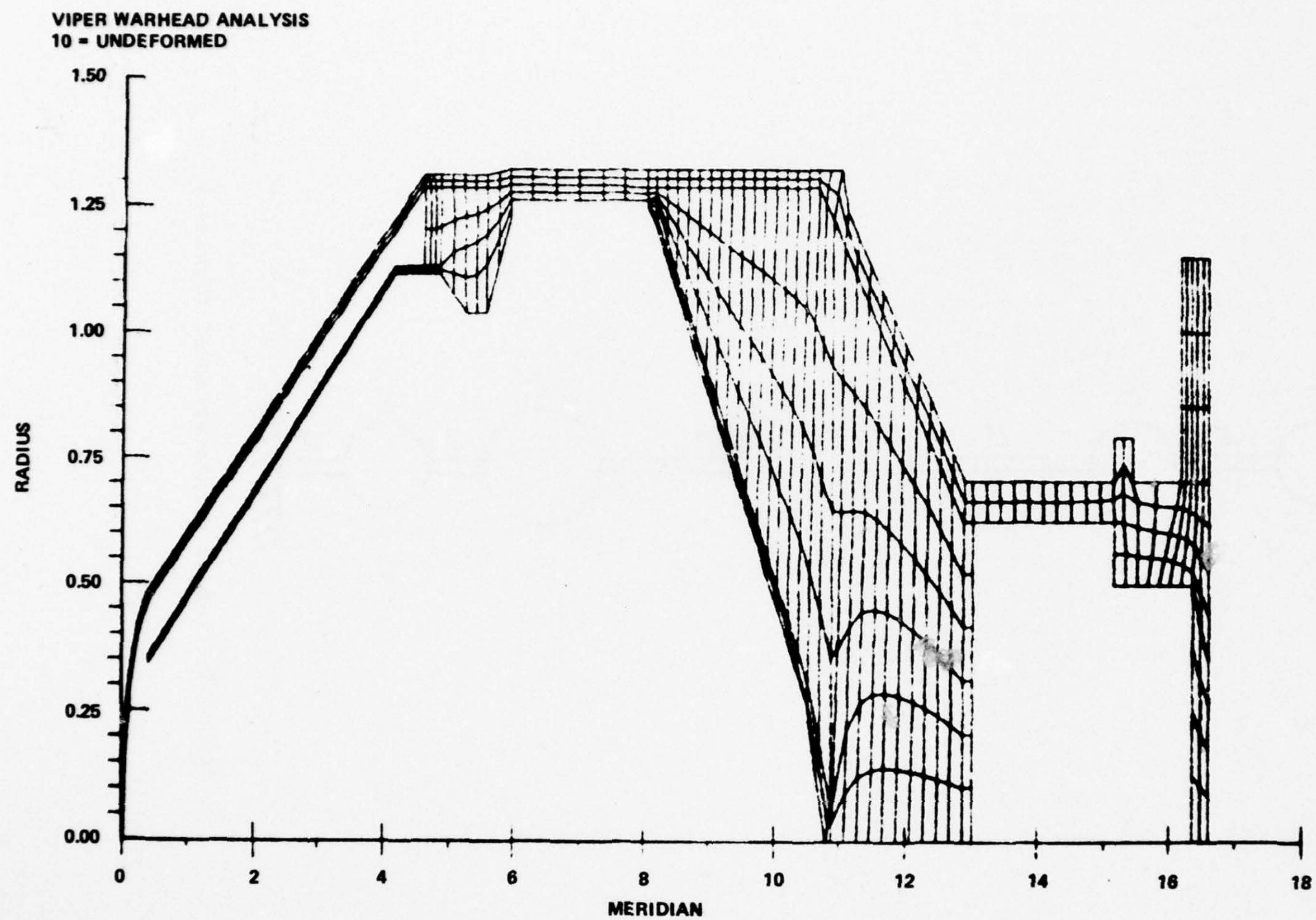

Figure 3. Finite element model (static).

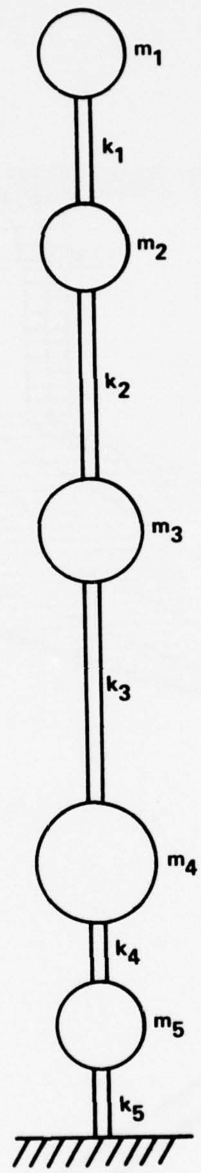

Figure 4. Lumped parameter model (dynamic).

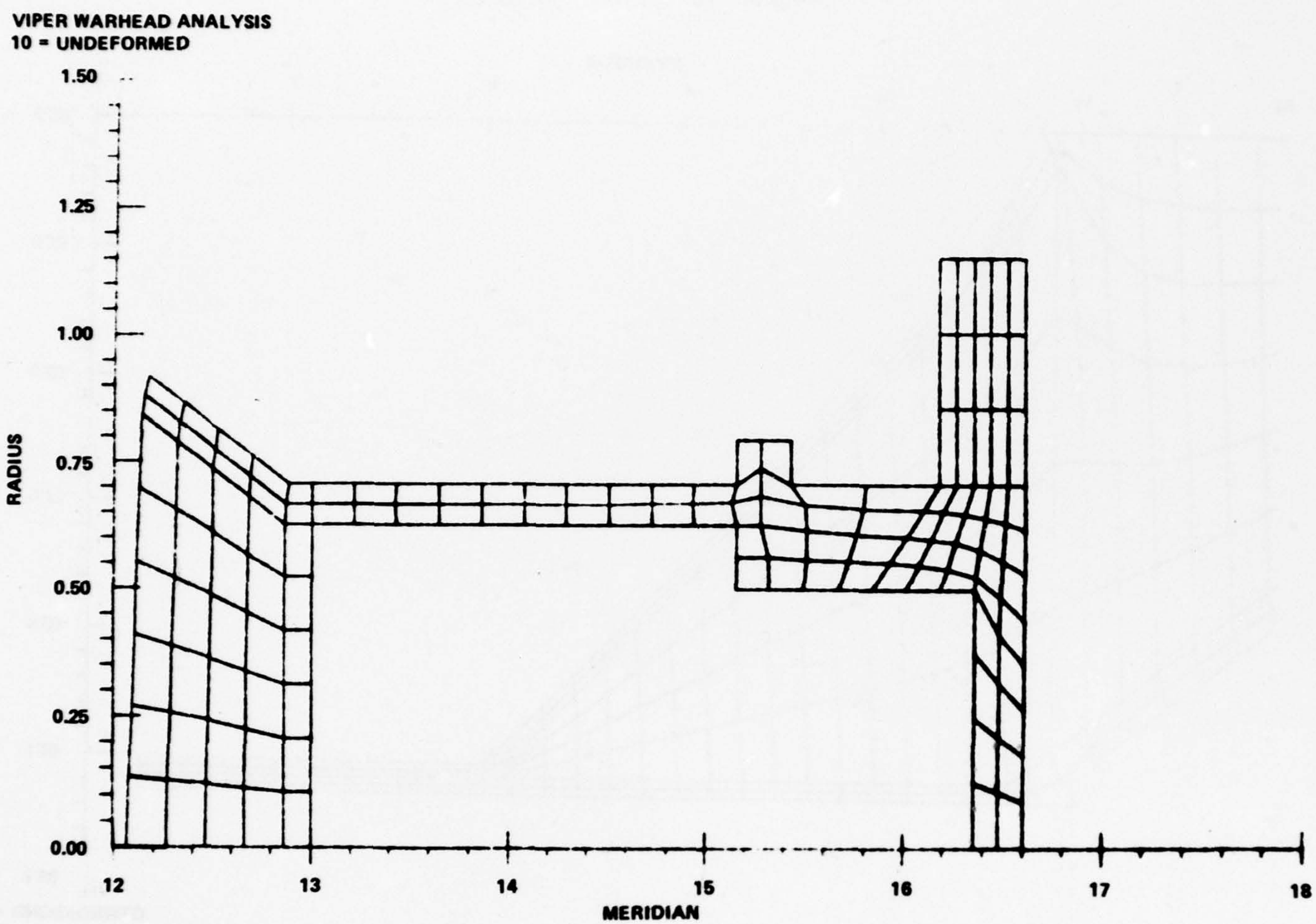

Figure 5. Detail of aft warhead body.

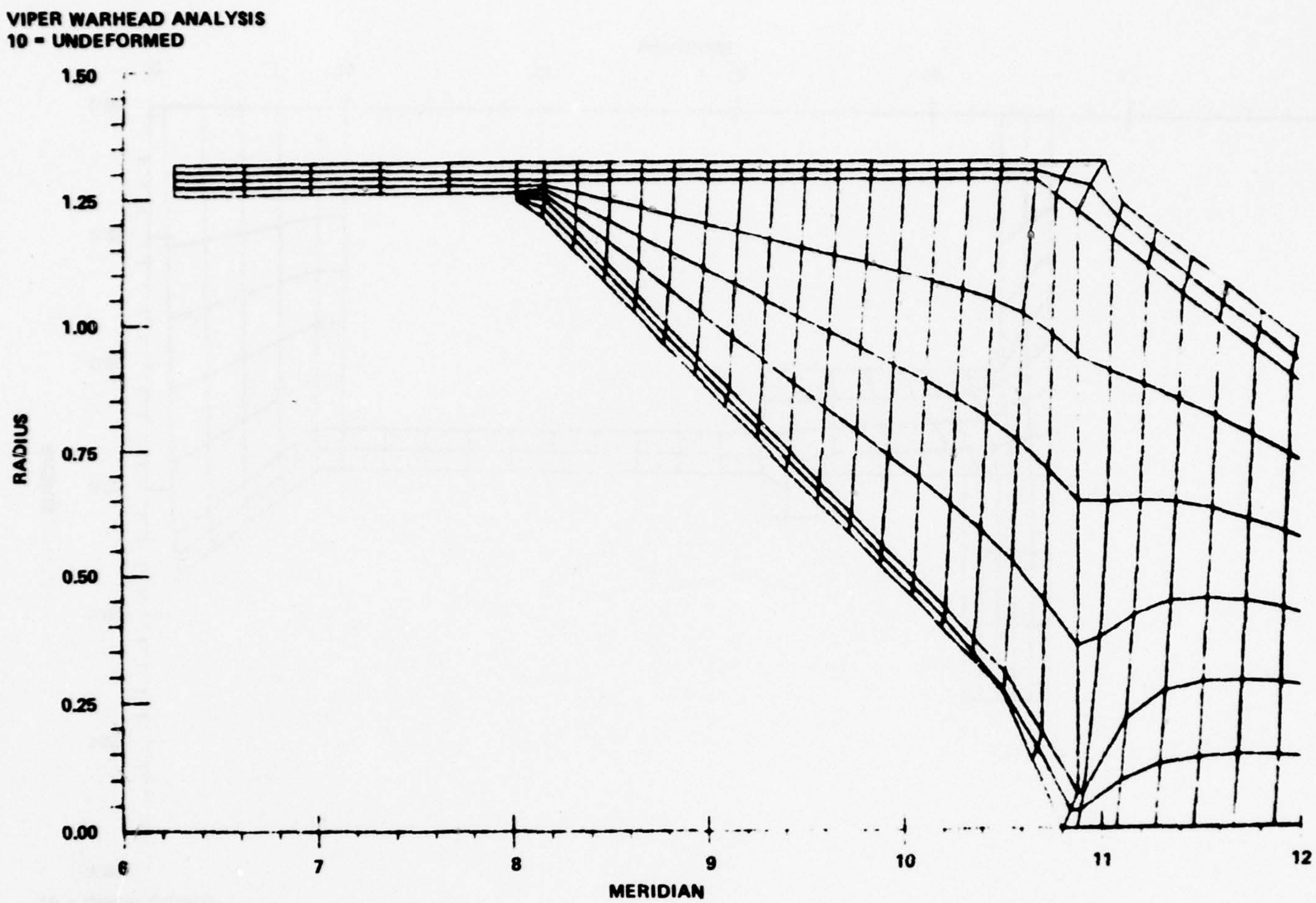

Figure 6. Detail of warhead.

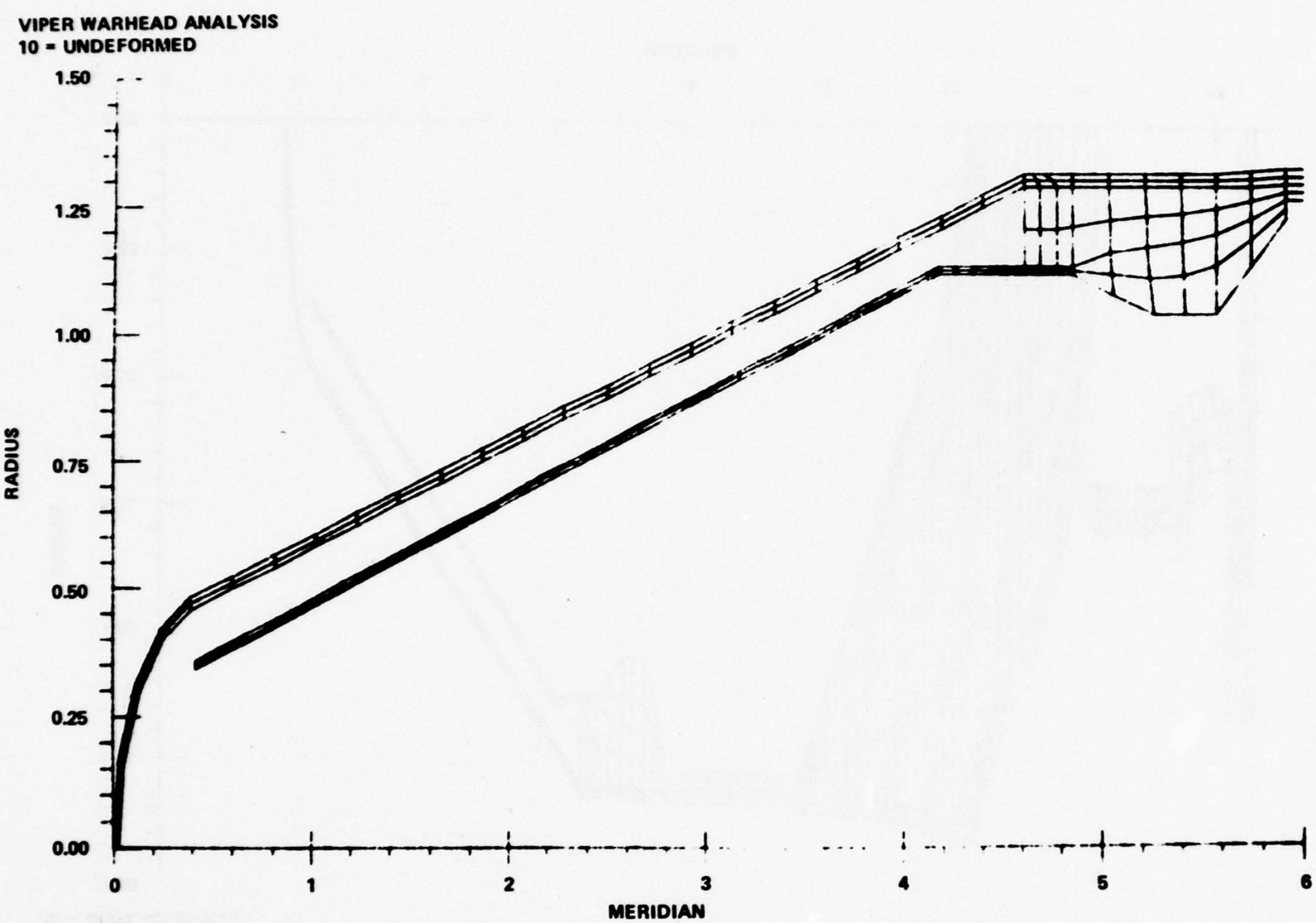

Figure 7. Detail of warhead.

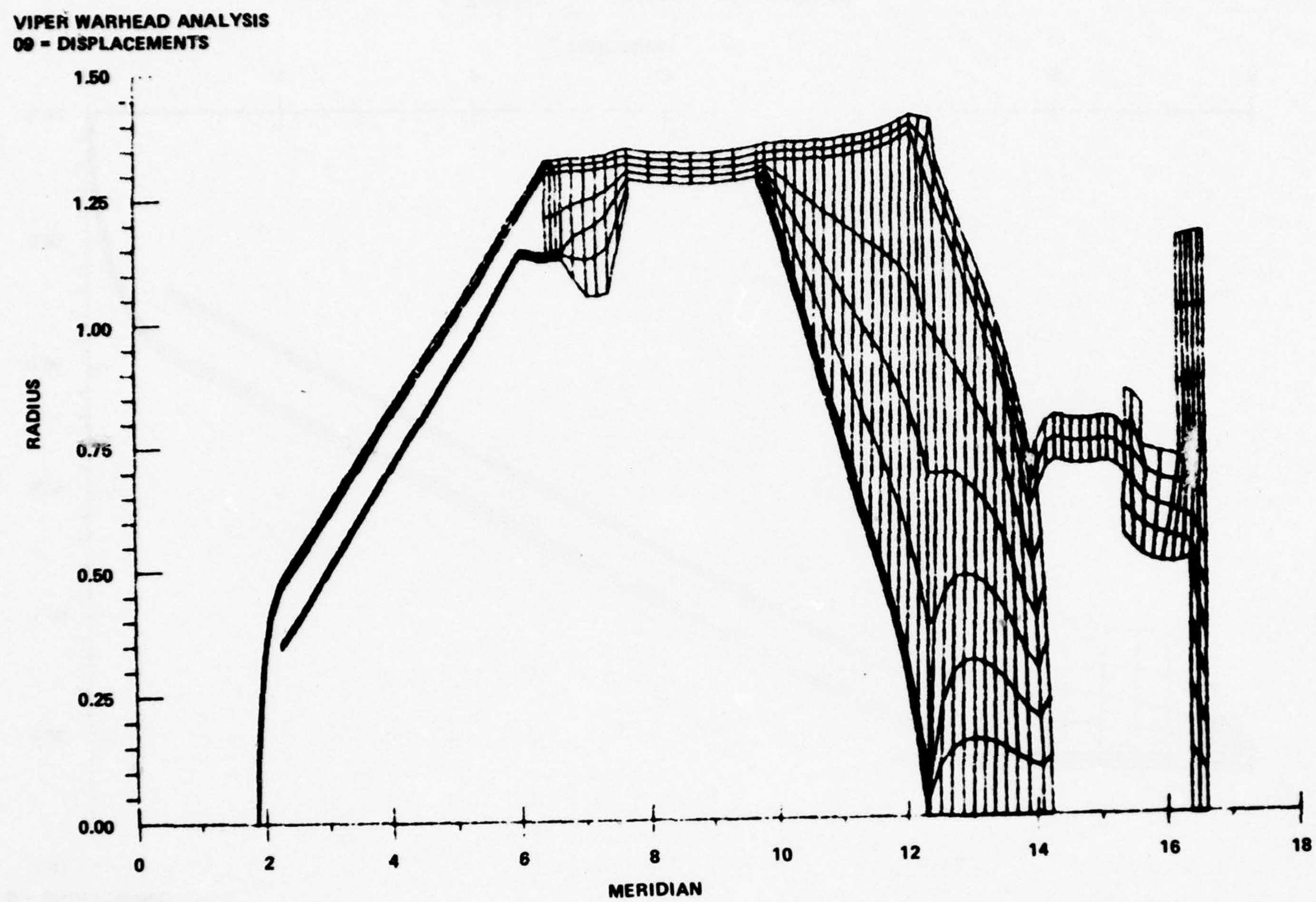

Figure 8. Deformed warhead.

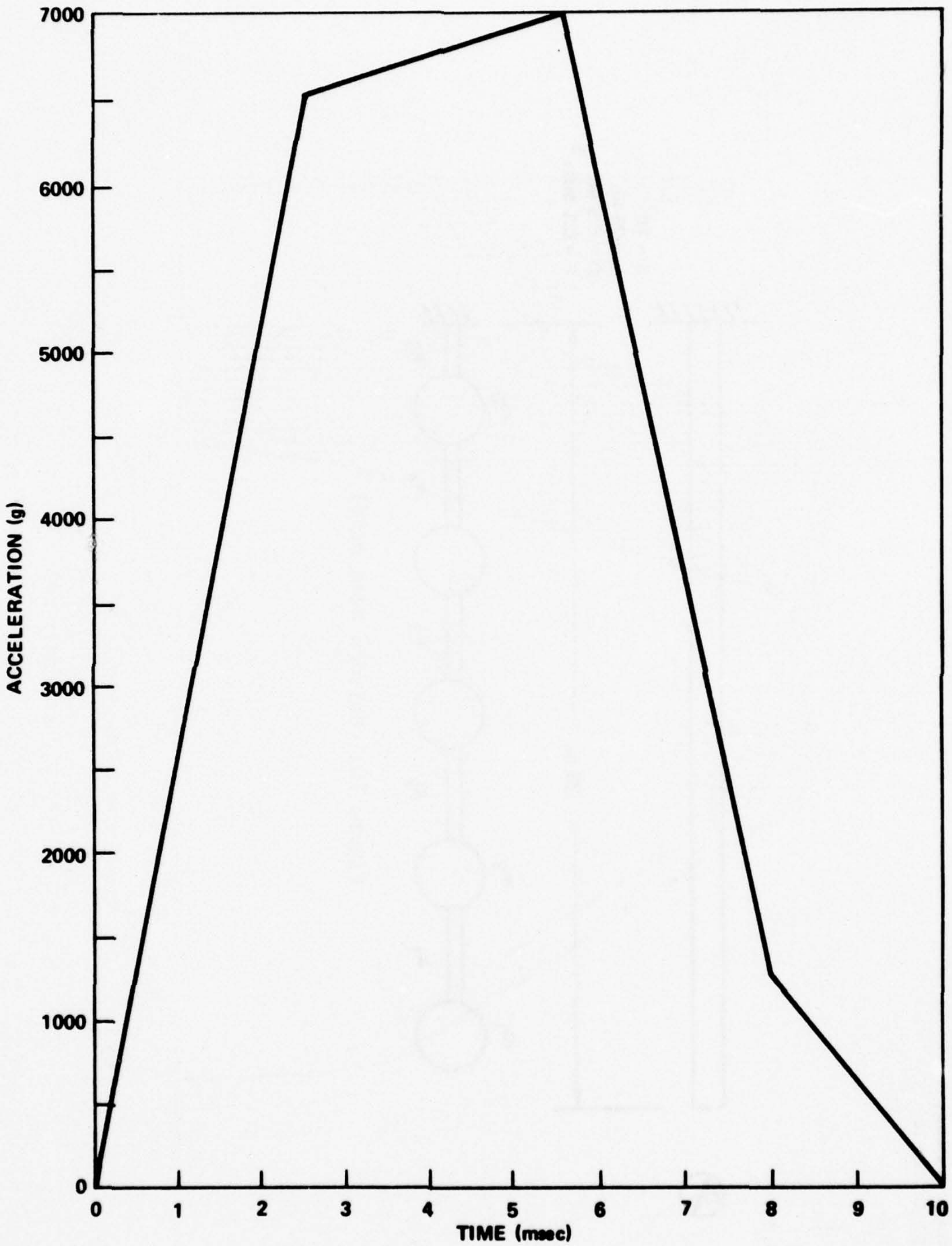

Figure 9. Rocket launch acceleration.

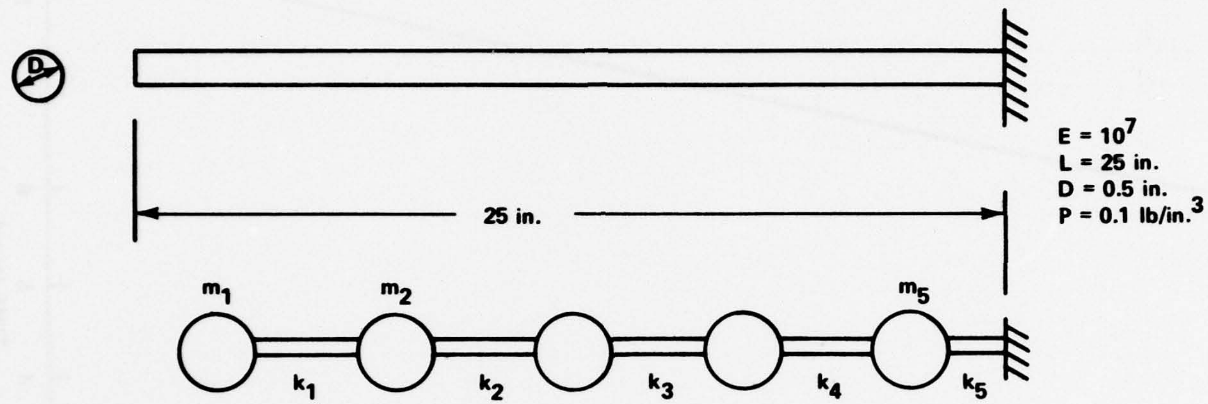

Figure 10. Uniform beam model.

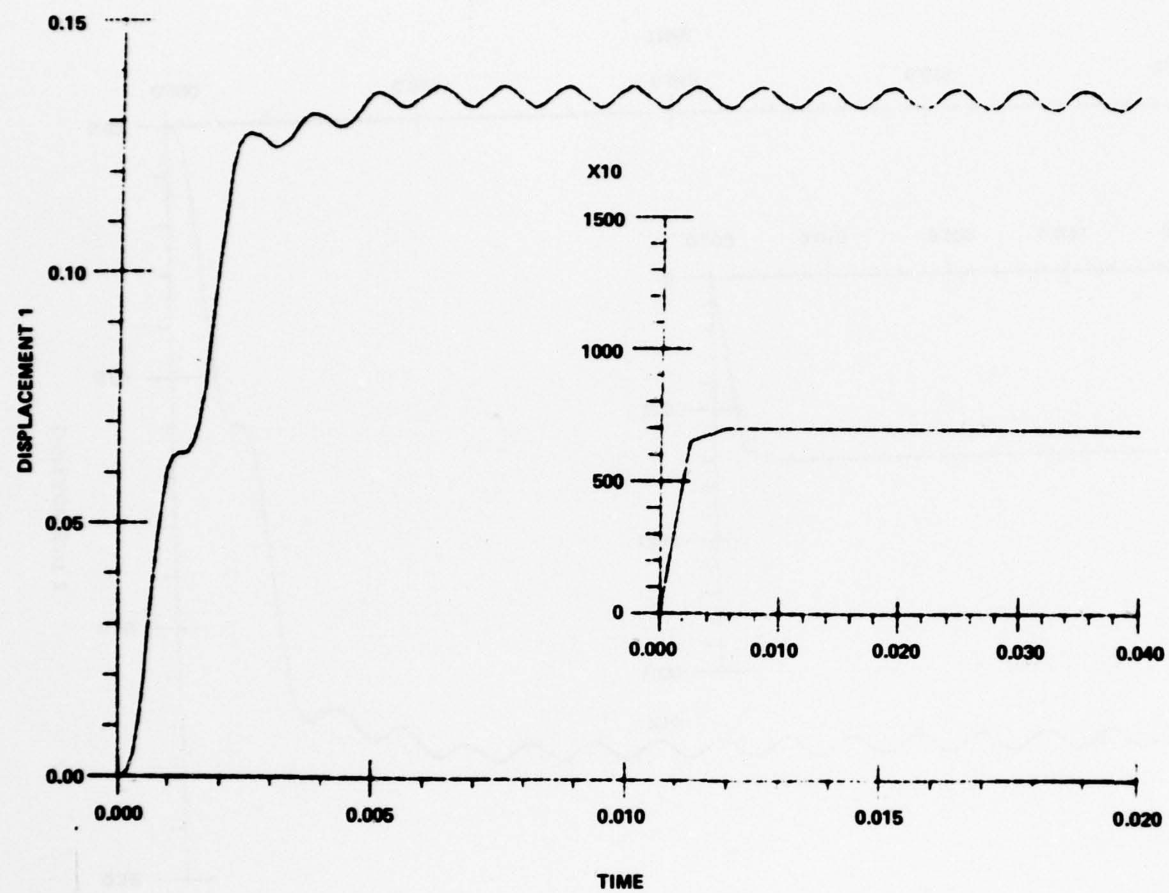

Figure 11. Uniform beam mass 1.

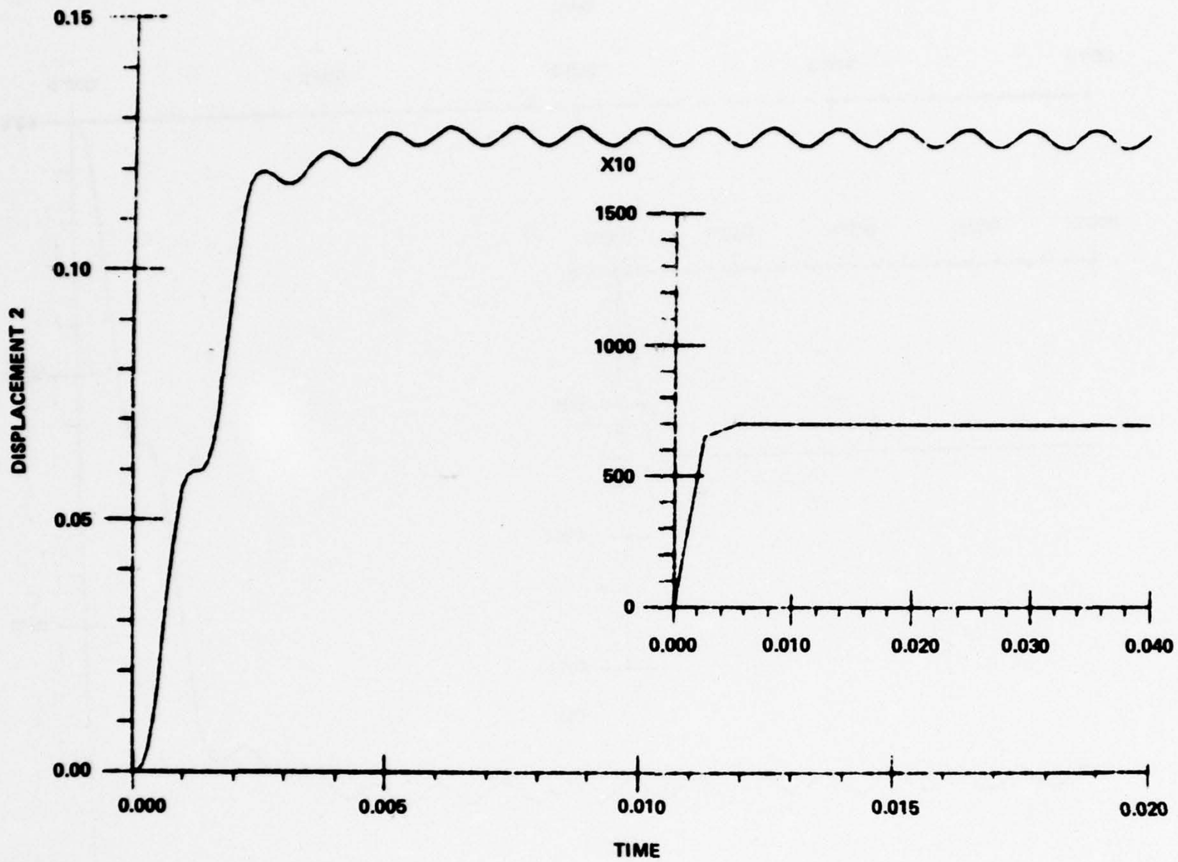

Figure 12. Uniform beam mass 2.

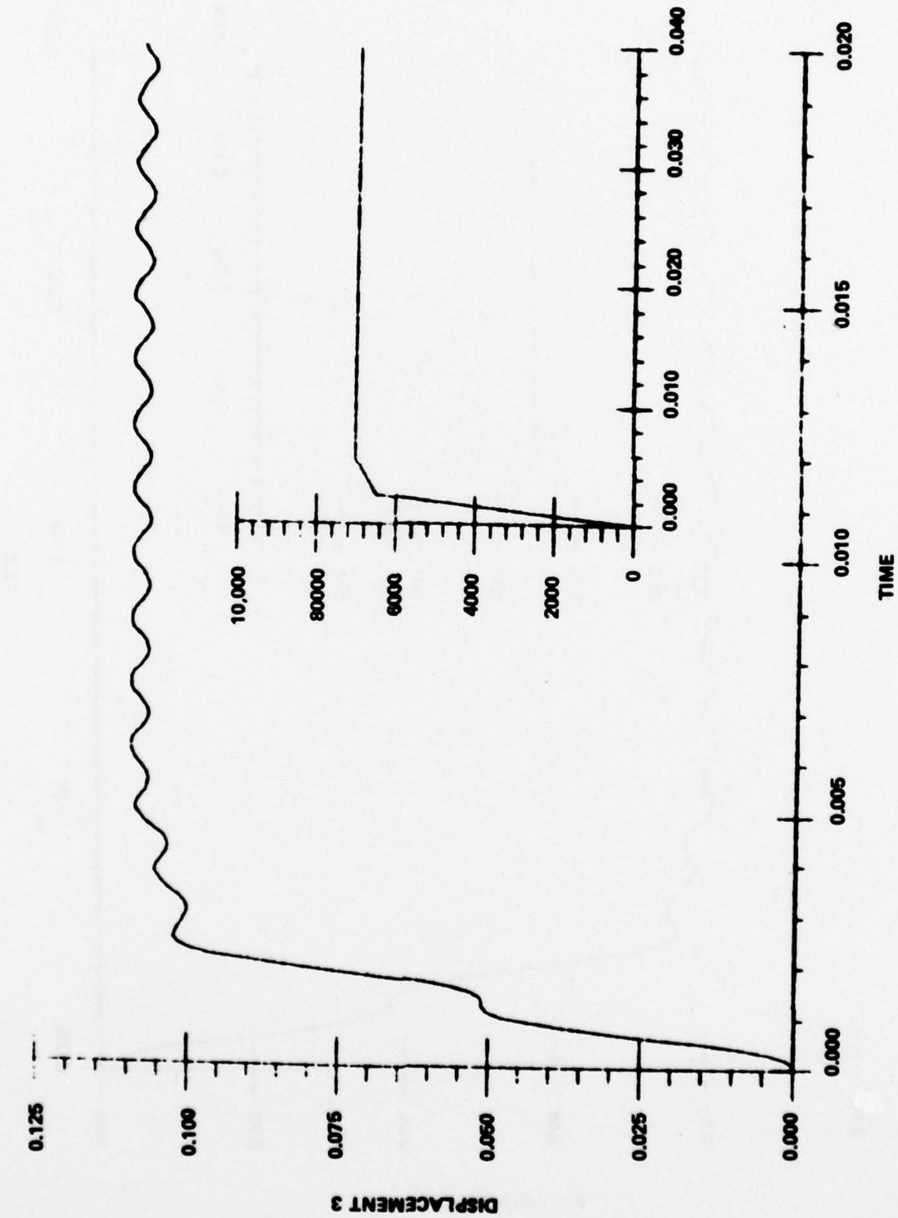

Figure 13. Uniform beam mass 3.

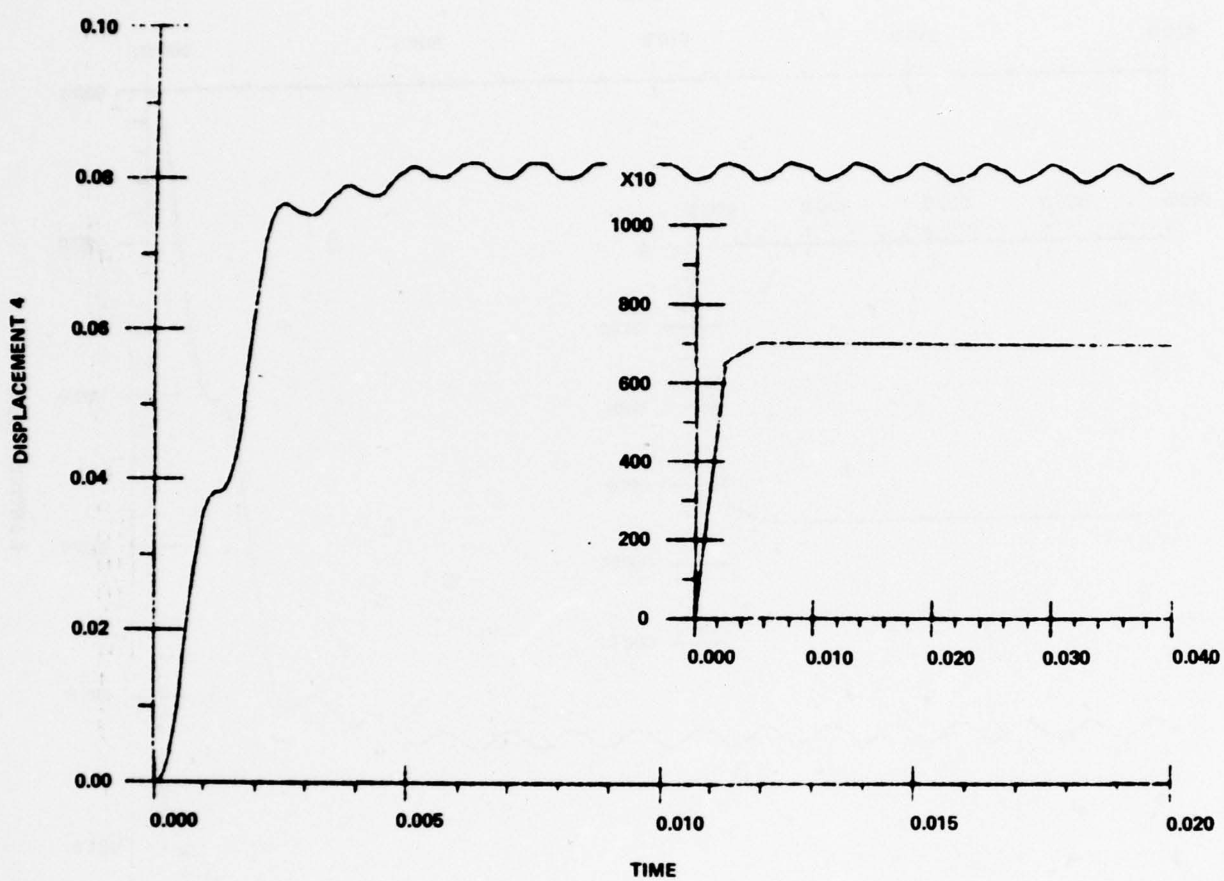

Figure 14. Uniform beam mass 4.

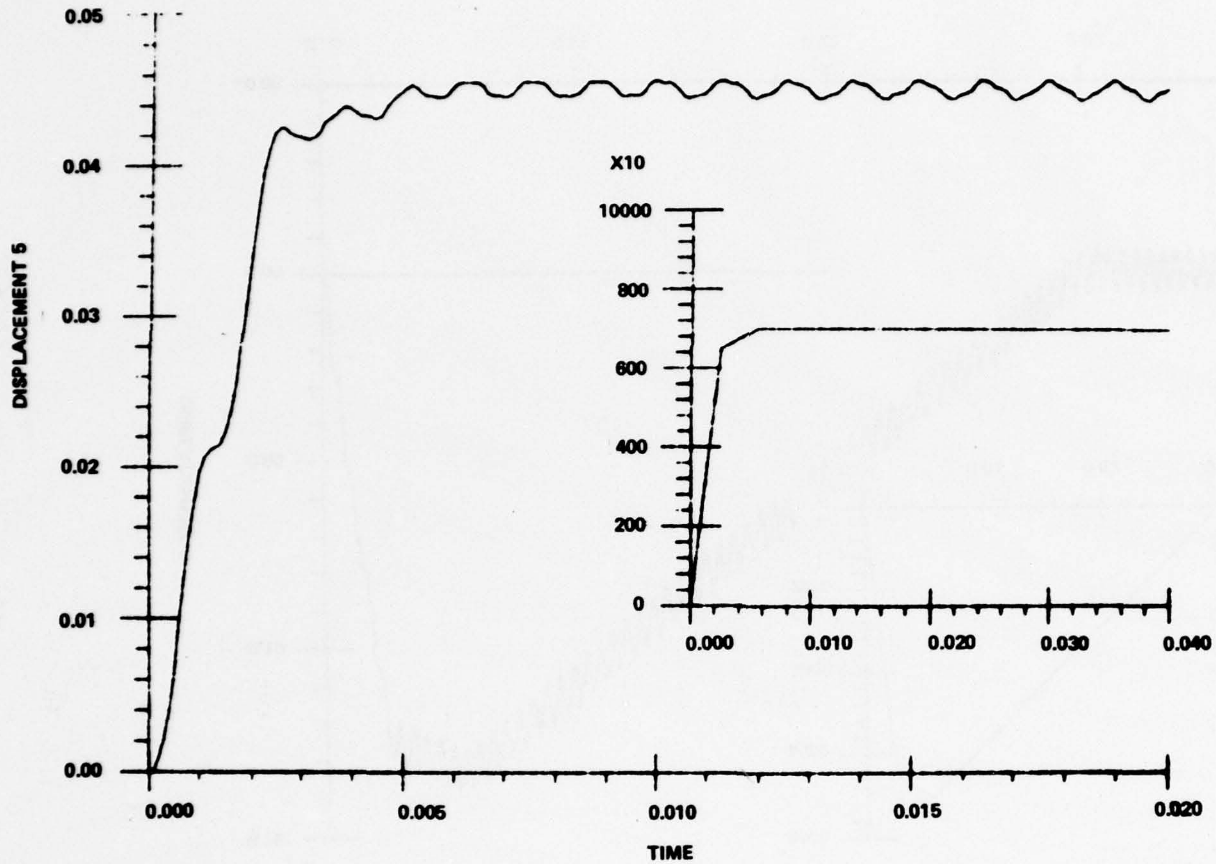

Figure 15. Uniform beam mass 5.

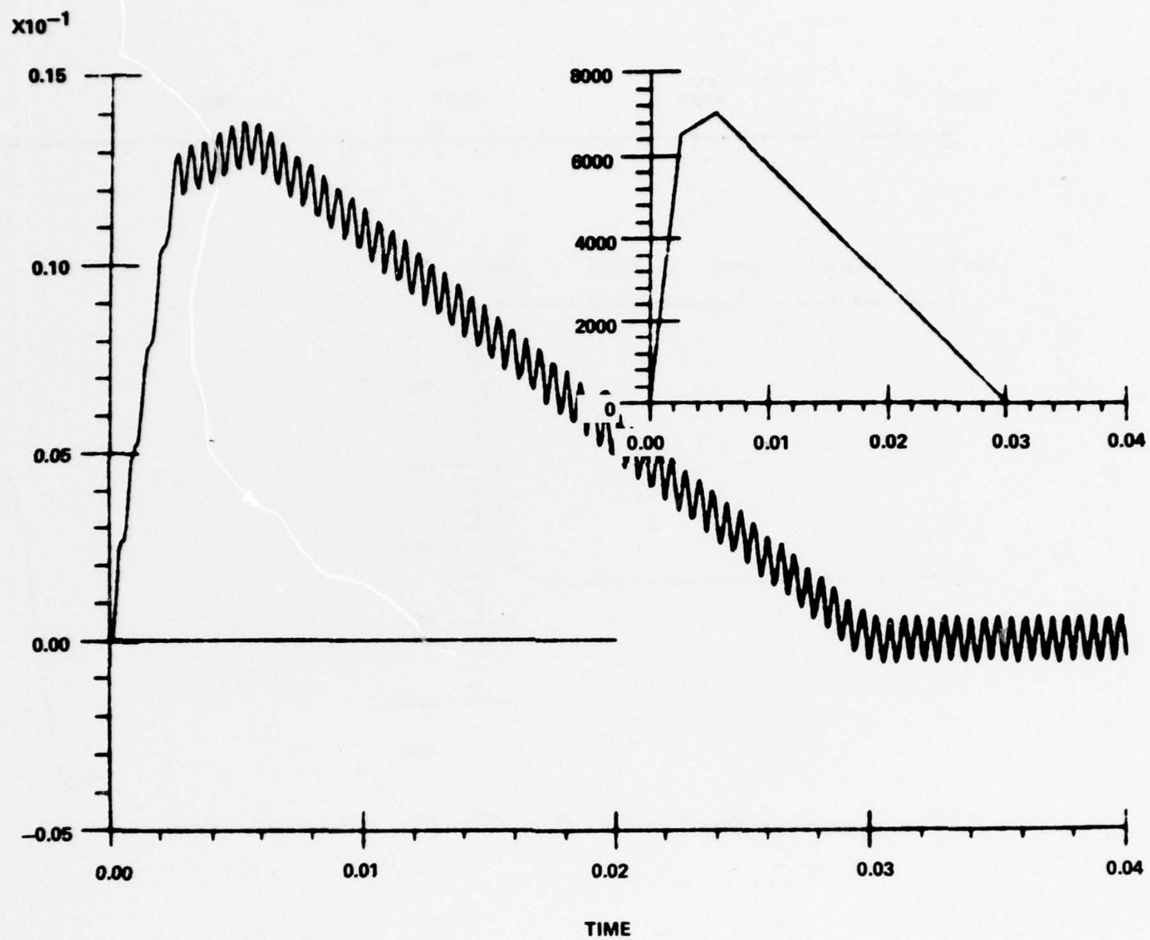

Figure 16. Case 1.

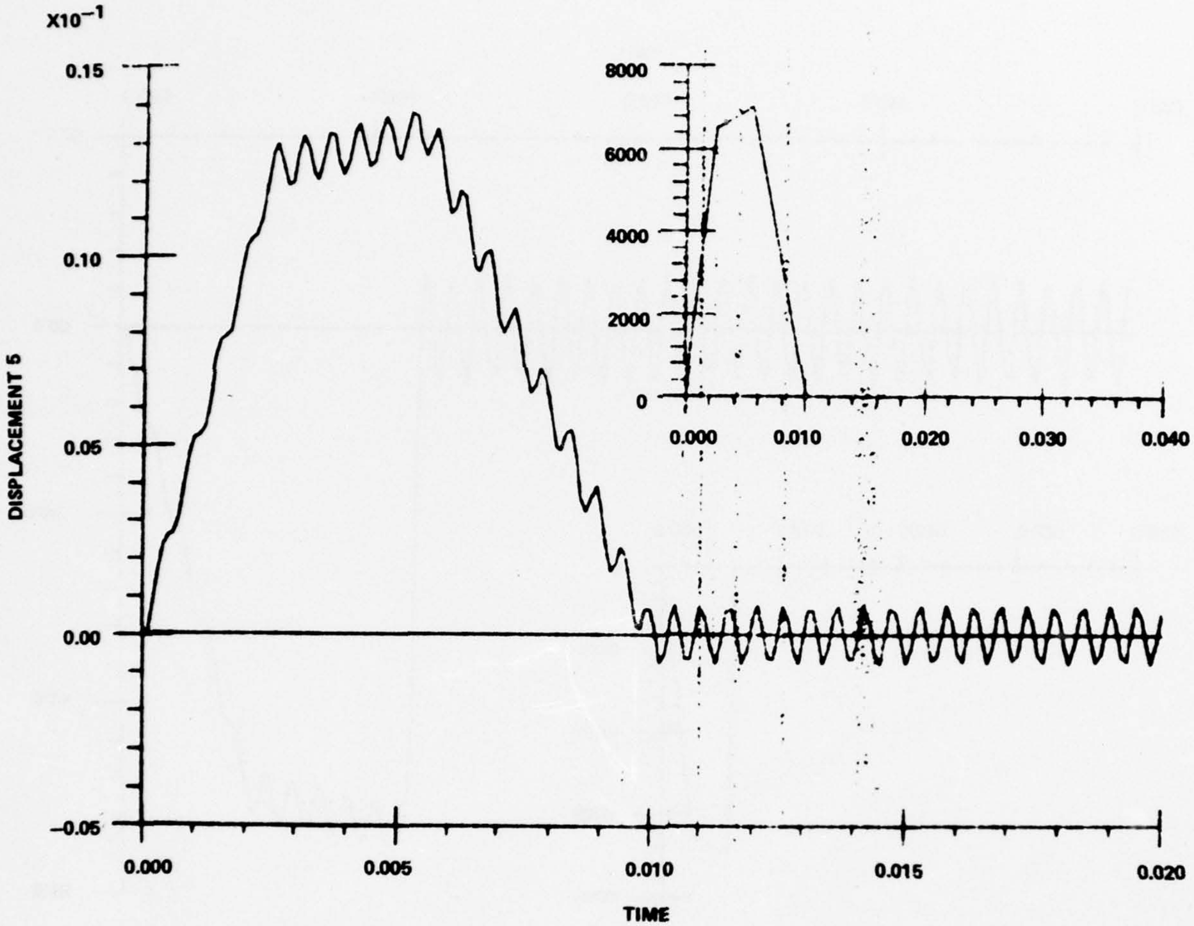

Figure 17. Case 2.

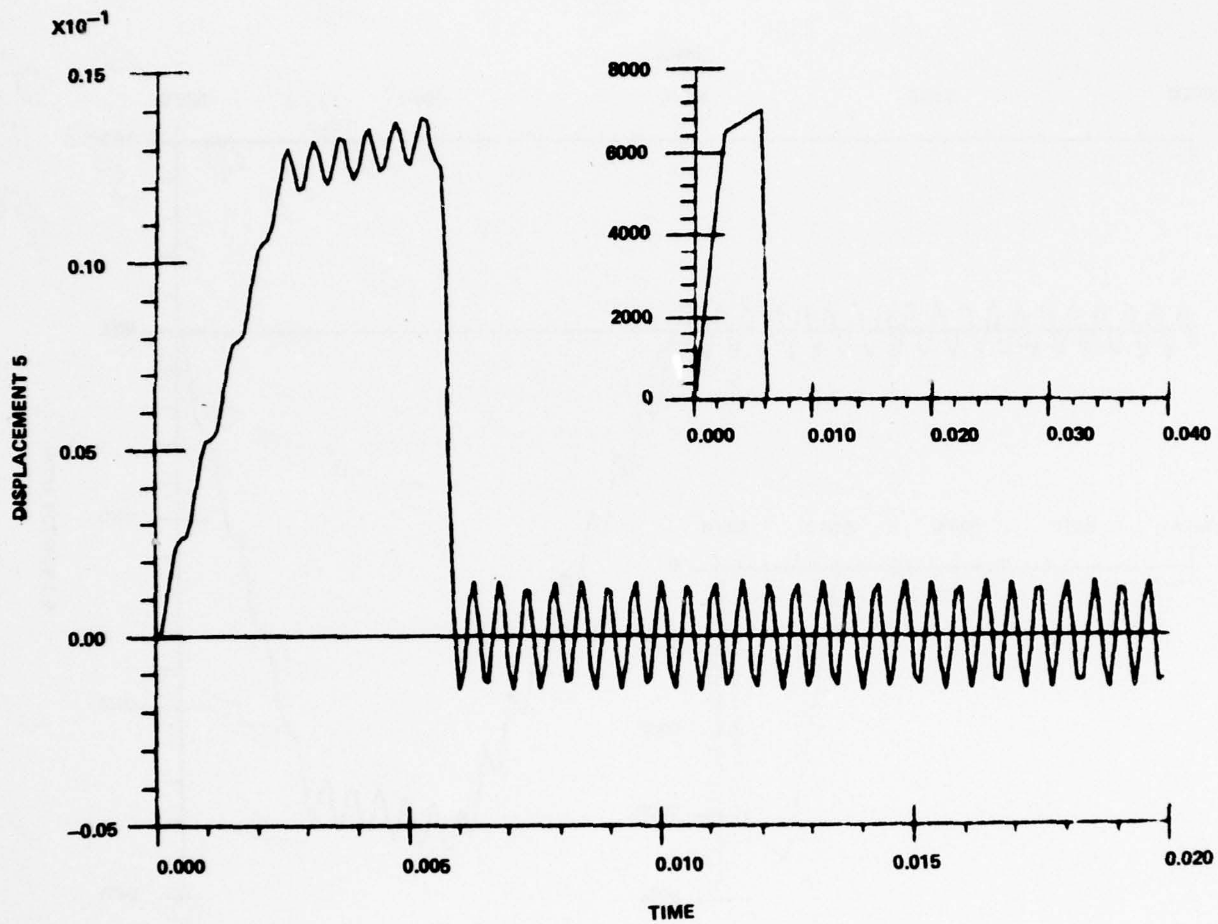

Figure 18. Case 3.

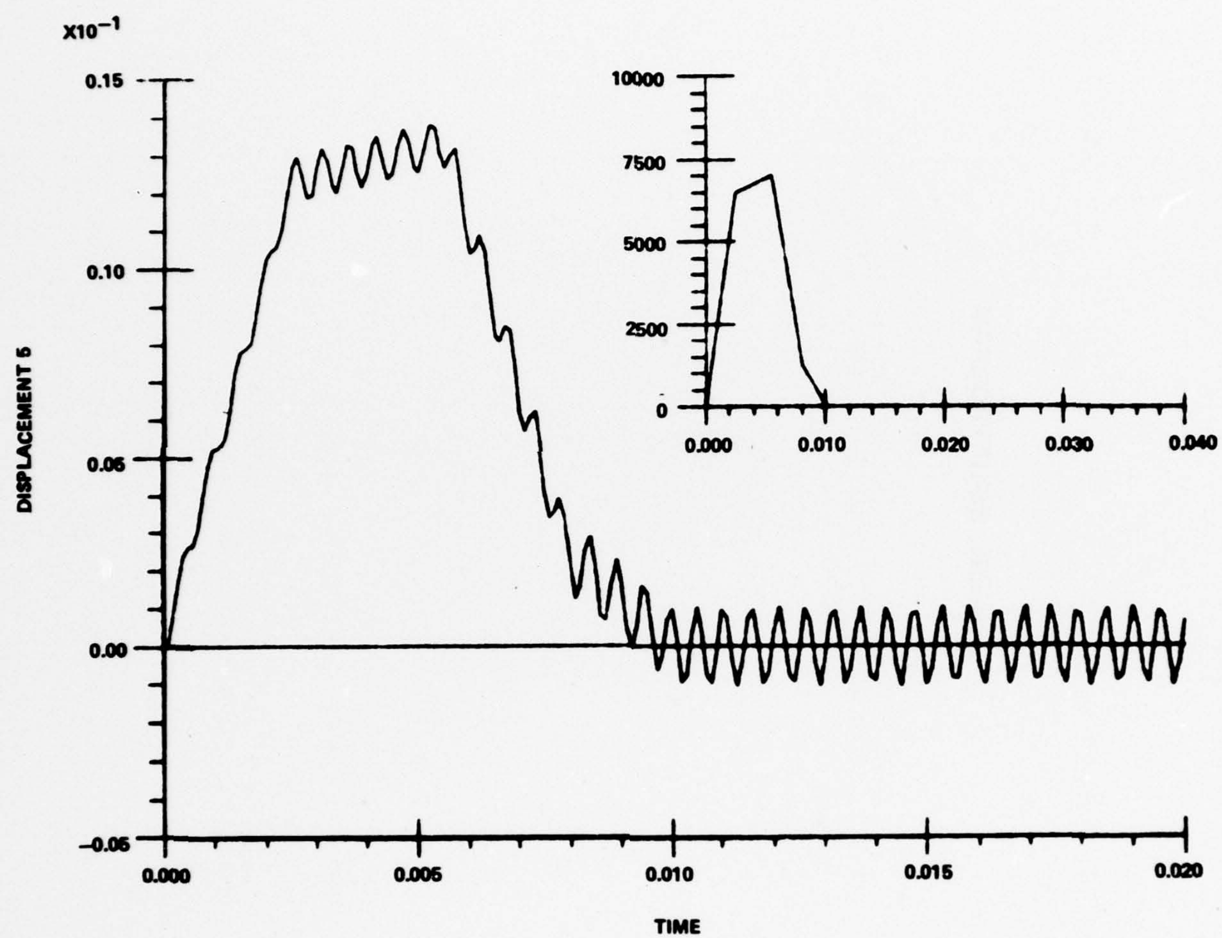

Figure 19. Case 4.

Appendix. INPUT PROGRAM

```
      PROGRAM MAIN(INPUT=65,OUTPUT=65,TAPE6=OUTPUT,TAPE2=513,
     1TAPE5=65)
      DIMENSION VT(11),W(3)
      DIMENSION X(1000),Y(1000),IXST(4),IYST(14),INUM(5)
      COMMON/FORC/XT(6),YT(6)
      EXTERNAL DESUB
      DATA IXST/84,73,77,69/
      DATA IYST/68,73,83,80,76,65,67,69,77,69,78,84,32,32/
      DATA INUM/49,50,51,52,53/
      DATA XT/0.0,0.0025,0.0055,0.008,.01,1./
      DATA YT/0.0,6500.,7000.,1250.,0.,0./
      REWIND 2
      TMAX=0.02
      NP=1
      J=0
      IC=0
      DEL=.00001
      DELMN=.5*DEL
      WRITE(6,1000) (I,I,I=1,5)
      DO 100 I=1,11
  100 VT(I)=0.0
      WRITE(2) VT(1),VT(2),VT(4),VT(6),VT(8),VT(10)
      WRITE(6,1100) VT(1),(VT(I),I=2,10,2),
     1(VT(K),K=3,11,2)
  200 J=J+1
      CALL SSIMDE(VT,W,DEL,DELMN,10,IC,DESUB)
      IF(MOD(J,10) .NE. 0) GO TO 150
      WRITE(6,1100) VT(1),(VT(I),I=2,10,2),
     1(VT(K),K=3,11,2)
      NP=NP+1
      WRITE(2) VT(1),VT(2),VT(4),VT(6),VT(8),VT(10)
  150 CONTINUE
      IF(VT(1) .GT. TMAX) GO TO 250
      GO TO 200
  250 CALL INITT(0)
      DO 400 K=1,5
      IYST(14)=INUM(K)
      CALL BINITT
      REWIND 2
      DO 300 M=1,NP
      READ(2) X(M),VT(1),VT(2),VT(3),VT(4),VT(5)
  300 Y(M)=VT(K)
      CALL NPTS(NP)
      CALL XFRM(4)
      CALL YFRM(4)
      CALL CHECK(X,Y)
      CALL DSPLAY(X,Y)
      CALL MOVABS(20,550)
      CALL VLABEL(14,IYST)
      CALL NOTATE(500,20,4,IXST)
      CALL MOVEA(0.0,0.0)
      CALL DRAWA(TMAX,0.0)
      CALL SLIMX(550,900)
      CALL SLIMY(450,700)
      CALL NPTS(6)
      CALL DLIMX(0.0,TMAX)
      CALL DLIMY(0.0,10000.)
```

```
      CALL CHECK(XT,YT)
      CALL DSPLAY(XT,YT)
      CALL SLIMX(150,900)
      CALL SLIMY(125,700)
      CALL BELL
      CALL TINPUT(ICR)
      CALL ERASE
  400 CONTINUE
 1000 FORMAT(1H1*  TIME  *5(* X(*I1*)/X DOT(*I1*) *))
 1100 FORMAT(1H F8.5,5E15.7/9X,5E15.7)
      END
```

```
      SUBROUTINE DESUB(VT,F,J)
      COMMON/FORC/XT(6),YT(6)
      DIMENSION VT(1)
      CONS=1.E8
      G=0.0
      IF(MOD(J,2) .EQ. 0) CALL INTERP(VT(1),XT,YT,6,2,G,NERR)
      G=G*386.4
      GO TO(10,20,30,40,50,60,70,80,90,100),J
   10 F=VT(3)
      GO TO 200
   20 F=-(64.00*(VT(2)-VT(4)))*CONS+G
      GO TO 200
   30 F=VT(5)
      GO TO 200
   40 F=(32.*VT(2)-80.00*VT(4)+47.00*VT(6))*CONS+G
      GO TO 200
   50 F=VT(7)
      GO TO 200
   60 F=(13.00*VT(4)-24.0*VT(6)+11.*VT(8))*CONS+G
      GO TO 200
   70 F=VT(9)
      GO TO 200
   80 F=(7.00*VT(6)-19.00*VT(8)+13.0*VT(10))*CONS+G
      GO TO 200
   90 F=VT(11)
      GO TO 200
  100 F=(47.00*VT(8)-67.000*VT(10))*CONS+G
C 200 WRITE(6,1000)J,F,G
  200 RETURN
 1000 FORMAT(1H * J =*I5,5X* F = *E15.7,5X* G = *E15.7)
      END
```

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